OUR UNIVERSE OF STARS

By Professor ERIC DOOLITTLE
THE FLOWER OBSERVATORY, UNIVERSITY OF PENNSYLVANIA

THE observer who stands out under the heavens on any clear, moonless night will see the light of far distant suns shining upon him in whatever direction he may turn. If he is fortunate enough to be so far away from artificial lights, and in so clear an atmosphere that the background of the sky is nearly black, the stars that surround him seem almost innumerable. He knows that all of these are great suns, many of them far hotter and brighter than our own sun, and that the nearest is so far away that its light has spent several years in coming to him, although light travels with the enormous speed of 186,330 miles a second. It can not be long before there comes to him some realization of the immensity of the great cloud of suns in which we are immersed.

Most striking and interesting of all to the naked eye is the Milky Way, that

> Broad and ample road whose dust is gold,

so very bright and narrow in Cassiopeia, but much wider in Cygnus, where begins that most remarkable feature known as the Great Bifurcation. Here the Milky Way branches into two parts. The western branch is the brighter until Aquila is reached, where it diverges still farther to the west, and comes almost completely to an end in Ophiuchus, to begin again in Scorpius. The eastern branch meanwhile grows narrower and remains bright, until it passes below the ground in the south. Between Aquila and the horizon is the most irregular region of the entire structure. Here suns are heaped together into great clouds which alternate with faint, or almost absolutely vacant, spaces.

When a great telescope is turned in any direction, the field of view is filled with stars, which become more densely packed together as the Milky Way is approached; indeed there are parts of this which can not be resolved into separate stars, even with the most powerful optical aid. And when a delicate photographic plate is exposed for many hours to any part of the heavens, the images of continually fainter and fainter stars appear upon it, until a record is secured of objects far too faint to be seen in any telescope. There are also revealed innumer-

able additional star-clouds and star-clusters, double and variable stars, and, in short, all of the objects the study of which makes up modern sidereal astronomy.

Evidently, the star cloud which surrounds us is of almost infinite complexity. It is no wonder that Sir William Herschel, its first explorer, became wholly absorbed in his work, and that his devoted sister, Caroline, sat, night after night, recording his observations until her feet were frozen to the ground. Not only did Herschel describe and catalogue for the first time thousands of double stars, nebulas, and other objects, but he sought to get some approximation to the form of the cloud of suns of which we are a part. This he did by counting vast numbers of stars seen in different directions and assuming that the relative distances of the stars could be found from their comparative brightness; that the fainter stars, on the whole, appeared faint only on account of their great distances from us. Thus he reached the conclusion that our universe has roughly the form of a grindstone, the greatest dimension lying in the direction of the Milky Way, and our sun being near the center.

But unfortunately, this assumption of Herschel with regard to the fainter stars can only very roughly be said to be true. We now know that the faint and bright stars are inextricably mixed in our star cloud; some of the nearest stars of the heavens are very faint and some of the brightest are so far away that their distances can not be directly measured. In addition to this, the surprising fact appears that the distribution of the stars depends to a large extent upon their comparative development. Those but little advanced from a nebulous stage congregate strongly in the direction of the Milky Way; those which have proceeded farther in their development surround us in a much less flattened cloud.

Taken as a whole, we now know that our Milky Way cloud of stars, though inconceivably vast, is far from being of infinite extent. It is also of a much more complex structure than described by Herschel. The stars of our visible universe are arranged in a flattened, lens-shaped form, the least distance through which is perhaps 2,000 light years, and of which the greatest diameter, extending in the direction of the Milky Way, is possibly four times as great. To a distance of about 300 light years in every direction, the distribution of the stars is nearly uniform. Beyond this the numbers rapidly fall off, until at a distance of 1,000 light years in the direction of the Poles of the Milky Way, the density is diminished to perhaps one fifth of that at the center. Around the edge of the great disc are the irregular clouds of the Milky Way, the inner edge of the nearest of which is perhaps 4,000 light years from us. Some astrono-

mers believe that there is an almost vacant space between the stars of our inner, flattened cloud and the complicated structure which surrounds it.

The individual suns which make up this complex cloud were, until very recently, believed to be moving indifferently in every direction, and in regard to a majority of them this is still believed to be true. But the surprising discovery was recently made that many of the stars belong to two great streams moving in both directions along a line which lies in the place of the Milky Way. There are thus two streams, the stars of which move in exactly opposite directions; one stream is not in front of the other, but they inter-penetrate one another in all parts of the heavens.

We can not yet definitely account for this great streaming of the stars. Dr. H. H. Turner has suggested that it may be explained by supposing that the stars of our universe move in very large but narrow orbits about the gravitational center of our cloud and that we view them going and returning from that center, from which our own sun is at a considerable distance. The strongest objection to this theory is that it requires too strong a congestion of stars near the center. While it is possible to suppose that one of the dense patches of stars in the Milky Way is the actually congested center of our stellar system, until much more data have been accumulated it will not be possible to come to any decision in regard to the theory.

All that has been said thus far is based on a study of the bright objects of our universe, those which can be seen in the telescope or which appear after a long exposure on a delicate photographic plate. But is all, or even a large proportion, of the matter in our universe gathered into self-luminous bodies? May there not be vast quantities which, like the meteorites and shooting stars which continually fall on our earth, are dark and so invisible to us? And may not the whole cloud be filled with a cosmic dust whose mass may far exceed the combined masses of all the brighter stars? If so, the gravitational pull of this diffused matter becomes of dominant importance in any inquiry into the future development of our system.

Fortunately, if the space within our star cloud is filled with finely divided matter, not only will the light from far distant suns be rendered fainter, but it will also be reddened in color. The reddening effect of a fine dust was very noticeable 36 years ago, when all of the air about the earth was filled with dust from an eruption of the great volcano, Krakatoa. This was a time of intensely red sunrises and sunsets which persisted for more than a year until, after the slow settling down of the dust particles, the air was again comparatively clean.

Thus, if finely divided matter exists in inter-stellar space, the more distant stars will be distinctly reddened. If a large number of stars known, or believed to be, very distant are arranged in a series according to their color, there will be a larger proportion of red stars than there are among those in the vicinity of our sun. Moreover, very blue stars will not be seen.

Studies based on this change of color have been carefully made by several observers, but the observations are very difficult and the results are discordant; the largest of the modern results is nearly three times the smallest. An average of the three best determinations indicated, however, that there is the equivalent of about 50,000 hydrogen molecules in each cubic centimeter of space. This is, of course, very far beyond the most perfect vacuum which we can attain artificially, and it would probably have no appreciable effect on the motion of the planets, but in a study of the development of our universe its effect becomes very important. For the total mass of this material would be no less than 150,000 times the estimated mass of all the stars in any large region of space.

An apparently more reasonable conclusion was reached three years ago by Dr. Harlow Shapley, of the Mount Wilson Solar Observatory, from a study of the bright cluster of stars in Hercules, and several other spherical clusters. This is the brightest star cluster visible to northern observers; it is almost overhead in the early evenings of July, and indeed is in excellent position for observation throughout the summer. In this wonderful aggregation of suns, more than 50,000 separate stars have been counted, down to the twenty-first magnitude, and the whole number must be vastly greater than this. The Hercules cluster is very remote from us; its distance is so great that the light of its stars occupies some 30,000 years in coming to us. Thus, it is wholly beyond the borders of our Milky Way universe.

Now when the stars of this very distant cluster are examined in regard to their color it is found that their distribution is almost indistinguishable from that of the stars which are near our sun. So little is this alteration that it is found to correspond to an extinction of but one per cent. of the intensity of a ray of light in travelling through space for 3,000 years.

From thirteen clusters examined in this way, Dr. Shapley has obtained practically identical results. As these objects lie in all different directions from us, the transparency of space is thus tested in these many directions. In each of them the amount of cosmic dust is found to be so small as to be almost negligible.

Inter-stellar space is, so far as cosmic dust goes, very clean. But there may be dark stars and dark nebulas in our star cloud

whose only effect is to cut off the light of whatever is beyond them. Of this nature, probably, are some of the dark spaces in the Milky Way, recently photographed and discussed by Dr. E. E. Barnard. No one can doubt that in some of these beautiful photographs we see the distant clouds of stars partially hidden by dark matter in front of them. But this opaque matter is very local. In general, there is no evidence of any dark material between us and the distant stars. We are therefore justified in estimating its total amount as but small compared with the whole mass of the stars.

If we therefore suppose that there is not an excessive amount of dark matter in our universe, we may proceed to inquire how the form of our star cloud will change under the action of the bright bodies which compose it. And it may be remarked that even if we assume the mass of dark matter as equal to, or even greater, than that of matter visible to us, the general character of our conclusions will not be altered.

But at the very outset we must decide between two wholly different modes of investigation. Until very recently it was believed that the stars can be compared to the molecules of a gas and that the laws applied in the theory of gases can be equally applied to our cloud of stars. These laws depend very largely upon the incessant collision and rebound of the gaseous molecules, by which the energy of motion is communicated from one to the other. Do the stars pass close to one another frequently enough (for actual collision is not necessary here), to make the kinetic theory of gases applicable, or are their close approaches relatively so infrequent that the gravitational pull of all of the stars of the cloud is all that need be considered?

Some light is thrown on this question by the quite recent discovery of several clusters of stars, ploughing directly through the cloud of stars which surrounds us. Perhaps the best known of these, and the one which has been most fully investigated, is the moving cluster in Taurus. This is a group of 41 bright stars, scattered over the whole western half of the constellation, though mostly concentrated about the Hyades, a study of whose motions shows that they are moving together through our star cloud. They are all moving in perfectly parallel lines with a speed of 28 miles a second. They, in fact, make up a globular star cluster, about 35 light years in diameter; this passed nearest us about 800,000 years ago; when viewed from the earth at this time the individual stars seemed even more scattered than at present. In 65,000,000 years the group will appear as a little round cluster of faint stars, five eighths the diameter of the full moon.

As we know the distance away of this cluster, it is easy to

find the absolute brightness of each of its stars. It is interesting to note that they are all far more luminous than our sun, the brightest ones exceeding the brightness of our sun by nearly 100 times. In the neighborhood of our sun we have nothing to compare with this brilliant assemblage of stars. Perhaps there are many fainter stars within the borders of the cluster, and belonging to it, but the motions of the fainter stars have not yet been so studied as to enable us to decide this point.

A second, very celebrated, cluster is known as the Ursa Major system because all of the stars of the Great Dipper are known to belong to it except the two extreme ones. It also includes the brightest star of the delicate little constellation of the Northern Crown and the very brilliant Dog Star, Sirius. This is a very flattened, disc-shaped cluster with an extreme diameter of about 110 light years; its thickness is only 8 light years. This cluster is moving somewhat more slowly than the cluster in Taurus, its speed being but 18 miles a second. All of its stars are far brighter than the sun.

Several other moving clusters are known. For our purposes, the striking fact to be noticed in connection with them is that though each one moves through the star cloud so that innumerable stars, distinct from the cluster, must be enveloped by it and afterward left behind as the swarm moves on, yet the stars of the cluster continue to move with an unchanged velocity and in parallel lines. It appears that even in these exceptional cases the chance near approach of two stars is a very unusual occurrence.

It is true that M. C. V. L. Charlier and other astronomers, who believe that the effects of near approaches should be taken into account, suppose that the stars remaining in the cluster are an insignificant remnant of a far greater swarm, most of whose members have been deflected by the stars of our cloud, and so driven away. But if this is so, it seems improbable that those which remain should have absolutely parallel and common motions. It seems more reasonable to suppose that from an original great swarm there should ensue all imaginable deflections from parallelism, from the slightest to those so great that the corresponding members have been driven out of the system altogether.

When, therefore, we consider the phenomena of moving clusters, and think too of the great distances which separate the stars, the evidence seems conclusive that the effects of occasional collisions may be altogether neglected. We need only consider the effects of the general gravitational attraction of the whole cloud of stars, and the kinetic theory of gases may be discarded in this connection.

But even with this restriction the problem is a very difficult one, calling for a development of the science of dynamics beyond any as yet available. However, certain general conclusions can be reached, even if the details can not be as yet filled in.

Whether we consider the kinetic theory of gases as applicable, or not, it appears that our universe is far from a form in which equilibrium can exist. It is in a state of rapid collapse. It may, under the gravitational pull of each of its suns, reach a condition of approximate equilibrium in 1,000,000,000 years. For an almost complete equilibrium, a duration 1,000 times as long is required. And under the kinetic theory, the times are about 100,000 times as great as these. At the expiration of these inconceivably great times, our cloud will probably be found of an approximately spherical form.

An interesting question here arises as to whether each star of our cloud will not have gone through its life long before these changes shall be consummated. Whether each of the bright stars will not have become cold and dark, ages upon ages before that remote time, and whether, if there are then any bright bodies in the universe, they will not be new stars, different from those we see now. For, according to the classic theory of Helmholtz, the life of a sun is a comparatively short one. This theory assumes that all of the heat radiated by a sun into space is caused by the slow contraction of the radiating body; every portion of the mass in thus falling toward the center loses its energy of position, which is transformed into heat energy and radiated away. It is a very simple matter to compute the past and future duration of our sun, for example, supposing that all of its heat is due to this source and that its radiation has remained sensibly constant. It is found that it could not have given off heat at its present rate for more than about 30,000,000 years, and that in 7,000,000 years from now it will have shrunk to one half its present radius; its increasing density will then probably cause its shrinking to be very much slower, and its heat and light will also begin to rapidly decrease.

But from geological considerations a much longer time is wanted. From a physical discussion alone, Sir George Darwin considered that "500 to 1,000 millions of years may have elapsed since the birth of the moon," and Dr. John Perry states that "if the paleontologists have good reasons for demanding greater times, I see nothing from the physicist's point of view which denies them four times the greatest of these estimates." And the paleontologists ask for a very long time to reasonably account for the grand upward development of life upon our earth. For many years it has been indeed evident that the contraction theory of Helmholtz is inadequate. Not that the con-

traction of the sun is not a true source of heat, and this cause must be ever in operation, but a greater source of energy must be looked for. And this, it is now thought, may be found in the atom.

During the past two decades, modern physicists have gotten very far away from the "small, round, smooth atoms" of Democritus. We know now that the atom is a very complex thing. With so-called radio-active substances it may be broken up, with the liberation of an immense amount of energy, the newer elements which result from the process having lower atomic weights than the original substance. Whether an appreciable amount of the heat and other energy emitted by the sun is of this sub-atomic origin, we do not know, but it seems not unreasonable to suppose that it is. For we can not even approximate to conditions as they must be found within the solar globe. It is true that the average temperature of the outside surface of the sun probably does not far exceed 12,000° Fahrenheit, but how very much hotter it is in the interior we have no means of knowing. The pressures, too, within the ball of the sun, are enormous. A very simple computation shows that at the depth of only 1,000 miles below the surface the pressure is nearly 6,000,000 tons on each square foot, an amount, of course, which we are wholly unable even to approach in our laboratories. It seems very probable that when subjected to these inconceivably great temperatures and pressures, atoms may be broken up, and a part, at least, of their sub-atomic energy may be liberated. And it is only necessary to suppose that a part of the energy of the atom is in this way radiated into space in order that the life of a sun, or star, may be almost indefinitely prolonged.

A rough image of the form which our stellar universe will take in the very remote ages of the future is furnished by those beautiful objects, the spherical, or globular, clusters of stars. The remarkable work of Shapley has shown that these are on the borders or wholly beyond the limits of our star cloud. They are isolated in space, and from probably irregular clouds have slowly taken the spherical form under the mutual pull of all of their stars. They are much smaller than our universe; the distance through them is measured in hundreds, instead of in tens of thousands of light years; they have therefore gone through their development much more rapidly. But it is very probable that our own far greater system will take approximately this same form, after a time so long that all times hitherto considered in astronomy shrink almost to nothing in comparison.